EVIDENCE OF A SOLAR INFLUENCE ON THE ATMOSPHERIC ELECTRIC ELEMENTS AT MAUNA LOA OBSERVATORY

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ABSTRACT

The monitored atmospheric electric elements at Mauna Loa Observatory, Hawaii, have provided good evidence of a direct solar influence on some of the electric elements recorded at the mountain observatory. An analysis of the data has shown that following a solar flare eruption, both the air-earth conduction current and the electric field, measured during fair weather at Mauna Loa, usually exceeded their established normal values.

For the 1-year measurement period from September 1960 to September 1961, nearly one-third of the days were considered as "disturbed" solar days due to solar flare activity. The mean value of the air-earth conduction current and the electric field on "disturbed" solar days exceeded that of the "quiet" solar days by about 10 percent.

During the month of July 1961, a period of spectacular solar activity, the highest sustained values of the year for the air-earth current and the electric field were recorded with the normal 24-hr. values being exceeded by as much as 35 percent, and for one 6-hr. period following a multiple flare burst, by 75 percent.

The influence of corpuscular solar radiation on the earth-ionosphere electric circuit and upon the global thunderstorm activity are discussed.

1. INTRODUCTION

Mauna Loa is a large mound-shaped mountain situated on the island of Hawaii, largest and southernmost island of the Hawaiian group. The summit rises 4.17 km. above the tropical Pacific and the Observatory is located on the northern slope at 3.4 km. The Observatory, remote from sources of pollution and located above the Pacific trade-wind inversion, provides a site where the sampled air properties are generally representative of the mid-Pacific troposphere above the austausch region (Cobb [5]). A complete description of the Observatory has been published by Price and Pales [17].

Several years ago, a 1-year measurement of the atmospheric electric elements was made at Mauna Loa Observatory (Cobb and Phillips [6]), for the purpose of establishing a "benchmark" measurement of the atmospheric electric climate. The establishment of an atmospheric benchmark at such a site is primarily important because the electrical conductivity of the air provides an index of the amount of fine-particle pollution suspended in the troposphere, at a site where the measurement is and will remain interpretable as representative of the global atmospheric state.

Continuous measurements were made of the potential gradient, the air-earth conduction current, and the polar conductivities, the parameters usually called the Ohm's law variables. In addition, continuous measurements were made of the large and small ion densities and the rate of production of the small ions. Figure 1 is a photograph of the instrument shelter. Ionic type measurements were made within the building in air drawn through the large chimney. Sensors for the electric field and the air-earth current were located in the ground plane shown in the foreground.

The large amount of fair-weather data that were recorded has established good baseline values for all of the electrical elements (Cobb and Phillips [6]). Further analysis of the data has revealed good evidence of an extra-terrestrial effect on some of the electrical measurements following disturbances on the sun.

2. SOLAR FLARES AND ATMOSPHERIC ELECTRIC MEASUREMENTS AT MAUNA LOA

The 1-year measurement period beginning September 1960 was also a period of considerable solar activity with 28 solar flares of Class 3 or greater and 42 magnetic storms being observed (Lincoln [13]).

An analysis of the year's data has revealed that following a solar flare eruption, both the air-earth current and the electric field, measured during fair weather at Mauna Loa, usually exceeded their established normal values. It is difficult, from a single event, to distinguish solar flare effects from normal terrestrially controlled variations of the electric field and the air-earth current. Summarizing

FIGURE 1.—Atmospheric electric station at Mauna Loa.

TABLE 1.—*Average values of the air-earth current and the electric field for "quiet" and "disturbed" solar days*

	Days	Electric field (volts/meter)	Air-earth current (amps/meter^2)
Quiet sun	256	116	5.3×10^{-12}
Disturbed sun	109	127	5.9×10^{-12}
Increase (percent)		9.5	11.3

the entire year's data, however, reveals an approximate 10 percent increase in the electric field and the air-earth current following solar flares (table 1).

The 109 "disturbed" solar days and 256 "quiet" solar days in table 1 were arrived at by defining the 6 days following each flare as "disturbed" solar days and all others as "quiet." This is not to say that the influence of a single flare persisted for 6 days. On the contrary, it was more likely to find an increase in the air-earth current and the electric field of less than a day's duration. These departures from normal, however, could occur in a few hours or up to several days following a flare, probably depending upon the energy and velocity with which the solar particles reached the vicinity of the earth.

Outbreaks of solar flares often take place with eruptions occurring simultaneously or in close sequence and thus the percentage increases in table 1 include the multiple effect of flares which occurred less than 6 days apart. When only time-isolated flares are considered, the percentage increases for the field and the current are reduced to about 5 or 6 percent.

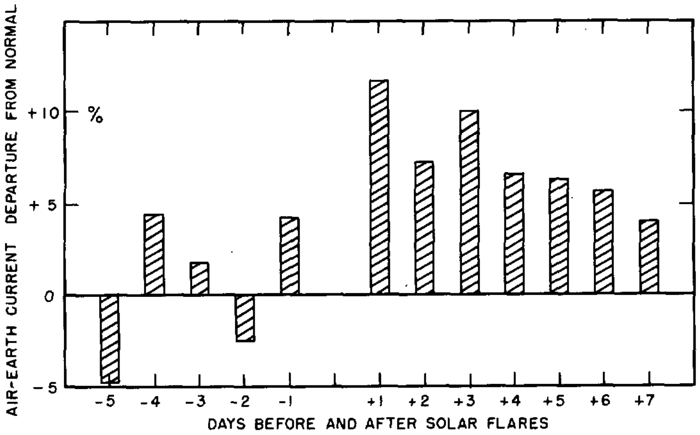

FIGURE 2.—Average daily departure from normal of the fair-weather air-earth current before and after solar flares.

In figure 2, the "departure from normal" of the air-earth current is summarized by days before and after the solar flares. The "normal" or "mean" air-earth current is obtained from the hourly tabulated values averaged for the entire year (Cobb and Phillips [5]). Since there is a predominant and persistent diurnal variation of both the electric field and the air-earth current (fig. 5), it is possible to compare the hourly measured values for any period in question with the corresponding hourly values averaged for the entire year. In such a manner, the persistent diurnal variation of the electrical parameters is statistically eliminated and the difference between one particular hourly value and the average yearly value for that hour is considered as the departure from normal.

An increase in the air-earth current, averaging 11.7 percent above normal (fig. 2), was found more likely to occur in the first 24 hr. following a flare and did so in approximately 80 percent of the cases. For the pre-flare days (fig. 2), only those flares were considered which were preceded by at least 5 "flareless" days.

Figure 3 is a plot of the daily departure from normal of the air-earth current at Mauna Loa from September 1960 to September 1961. Also shown is the day of occurrence of solar flares, major magnetic storms, and the dashed line representing the Bartels' magnetic character-figure [13].

As might be expected, there are many excursions of the air-earth current that cannot be correlated with solar activity. In several instances, however, there is good evidence of an increase in the air-earth current during solar flare activity and a decrease during "quiet" solar periods.

The solar flare influence on the electric elements was most clearly evident during the month of July 1961. This was a period of spectacular solar activity with 12 flares occurring during the last 20 days of the month. The highest sustained values of the year for the air-earth current and the electric field were recorded during this period with the normal 24-hr. values being exceeded by as much as 35 percent.

The chronological events of July warrant further inspection. The first 11 days were a nearly undisturbed solar period with no flares and only one magnetic storm, which occurred on July 4 and 5 [14]. Two major flares occurred at 1615 UT July 11 and at 1950 UT July 12. On July 13, the peak particle fluxes from these flares were detected near the top of the atmosphere (1,000 km.) by "Injun 1" satellite (Pieper, Zmuda, and Bostrom [16]). On July 15, two more flares were reported at 1433 and 1520 UT. At Mauna Loa, the air-earth current on July 15 was higher than for any other 24-hr. period of the year. For one 6-hr. period on July 15, the air-earth current exceeded its normal value by 75 percent, probably due to corpuscular radiation from one or more of the previous flares. The three highest air-earth current days of the year were recorded on July 15, 23, and 26. The large number of flares, however, makes it impossible to attribute particular surface measurement peaks to a particular flare.

July is a month of maximum global thunderstorm activity and it has been considered that the higher air-earth current during the month might have been the result of a natural abundance of thunderstorm activity during the Northern Hemisphere summer. (The connection between global thunderstorm activity and the fair-weather air-earth current is discussed in section 3.)

January is also a peak global thunderstorm month, being the Southern Hemisphere thunderstorm season. By contrast, however, January 1961 was a "quiet" solar month with no flares and the air-earth current remained mostly below normal. August 1961 was also a "quiet" solar month and the average air-earth current for the month was the lowest of the year. Thus it appears that seasonal variations in the world-wide thunderstorm activity are not responsible for the high air-earth current measured in July 1961.

November 1960 was another quite spectacular solar period which produced six major flares. Except for a sudden increase of 35 percent, 3 days after the double flare of November 5, the air-earth current did not remain above normal as it did during July 1961. Unfortunately, stormy weather during much of November limited the number of hours of fair-weather data and the observations may not be representative.

It has been considered that corpuscular solar radiation is the most likely extra-terrestrial element that could directly affect atmospheric electric measurements at the earth's surface. Unfortunately, corpuscular solar radiation is seldom measured directly. There are several indirect criteria, one of which is the Bartels' magnetic character-figure published monthly [13]. The Bartels' magnetic character-figure is a measurement of the disturbance component of the earth's magnetic field and in figures 3 and 4 an attempt has been made to correlate this parameter with variations from normal of the fair-weather air-earth current at Mauna Loa. Agreement between the two parameters is not very apparent in figure 3; however, the

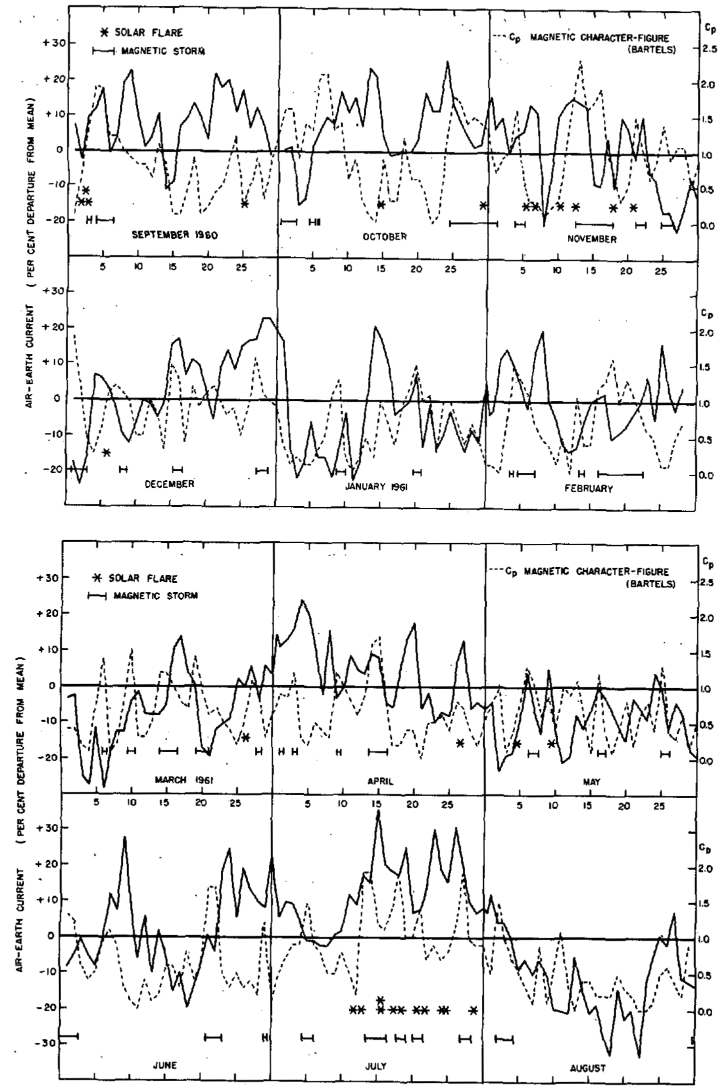

FIGURE 3.—Daily departure from normal of the fair-weather air-earth current at Mauna Loa Observatory from September 1960 through August 1961.

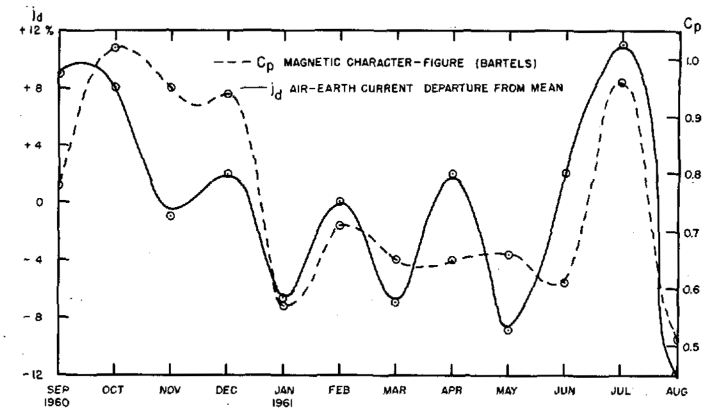

FIGURE 4.—Monthly variation of air-earth current departure from mean and the Bartels' magnetic character-figure from September 1960 to September 1961.

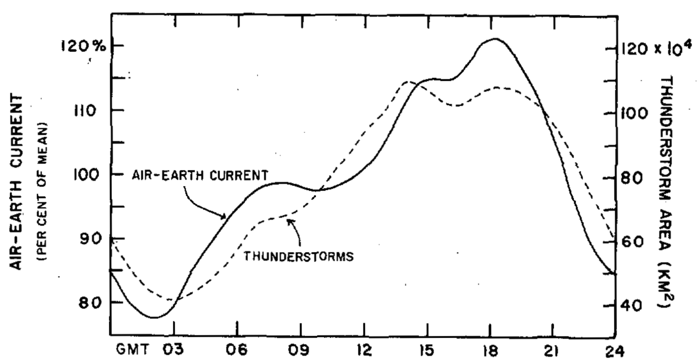

FIGURE 5.—Diurnal variation of the global thunderstorm area (Whipple [22]) and the fair-weather air-earth conduction current at Mauna Loa Observatory.

average monthly values of the same parameters (fig. 4) show remarkable correlation, particularly between the most "magnetically disturbed" months of October and July and the least disturbed months of January and August.

3. SOLAR CORPUSCULAR RADIATION AND THE EARTH-IONOSPHERE ELECTRIC CIRCUIT

In order to discuss the effect of corpuscular solar radiation upon the surface measurement of the air-earth conduction current, it is necessary to view the current flow from a global concept. The classical hypothesis of the global concept of atmospheric electricity views the earth and the ionosphere as highly conducting concentric layers separated by an imperfectly insulating atmosphere, thus forming a fairly good, even if somewhat leaky, condenser.

The existence of an electrical conduction current flowing from the air to the earth in fair-weather areas was detected by several scientists in the 16th and 17th centuries and later it was C. T. R. Wilson [23] who is credited with recognizing the role of the global thunderstorm activity in energizing the earth-ionosphere electric circuit.

The operation of the "Wilson Circuit" can be briefly summarized as follows: Over fair-weather areas of the earth, there is a downward transfer of positive charge which tends to reduce the positive potential of the ionosphere and to neutralize the negative charge on the earth. Over stormy areas of the globe, on the other hand, positive charge is transferred upward at a rate proportional to the total thunderstorm activity and of sufficient quantity to balance the fair-weather downward transfer of positive charge. In support of the Wilson hypothesis, the diurnal variation of the fair-weather air-earth current at Mauna Loa closely follows the world thunderstorm diurnal variation curve of Whipple [22] (fig. 5).

4. THE "EQUIVALENT POTENTIAL" LAYER

With respect to the earth-ionosphere condenser concept, the question arises: How effective a barrier is the outer condenser shell, or as it is often called, the equivalent potential layer?

It should be stated that the term "ionosphere" as used here refers to the 50 to 75-km. altitude range as the location of the outer shell of the atmospheric condenser since the region above 50 km. is sufficiently ionized that it is generally considered as a conducting electrostatic shield. It would seem more appropriate for the atmospheric electrician to adopt the term "C-layer" as defined by Schmerling [20] for the location of the upper conducting layer.

Because the C-layer is a highly conducting region, any space charge which is absorbed, for example, space charge transported by corpuscular radiation, will be distributed around the entire equivalent potential layer in a matter of minutes. It is generally agreed, however, that this conducting layer cannot be considered as a true electrostatic shield but rather as a changing, often non-equipotential layer. Kasemir [12], for example, calculated that the electric current flow above thunderstorms could penetrate the ionosphere and extend far out into space. Solar corpuscular radiation involves an opposite but perhaps similar aspect, that is, ionospheric penetration from the opposite direction.

It is perhaps significant that neither the ion density nor the ion production rate at Mauna Loa were affected during the "disturbed" solar periods, indicating that any changes in these parameters must have been confined to higher altitudes. Cole and Pierce [8] recently reported that stratospheric changes in conductivity would have an insignificant effect on the response of ground level observations of atmospheric electricity. They have calculated that 90 percent of the earth-ionosphere columnar resistance lies below 2.4 km. and thus changes in the upper portion of this column would not appreciably alter the total resistance for the vertical conduction current. In the case of mountain top stations such as Mauna Loa at 3.4 km. and the Zugspitze in Germany at 3 km. (Reiter [18]), however, the columnar resistance to the ionosphere is less than a tenth the resistance of the total column to sea level. At these two locations, at least, the electric field and the air-earth current apparently are responsive to changes in the atmospheric column above the mountain tops.

It would seem that any logical explanation of the post-flare phenomenon found at Mauna Loa must involve the penetration of the equivalent potential layer by ionizing corpuscular radiation. Cole, Hill, and Pierce [7], in a subsequent report to [8], have shown that even though the original electron energies are rapidly dissipated in the lower ionosphere, secondary ionization produced by Bremsstrahlen X-rays may penetrate to considerably greater depths in the atmosphere. Bremsstrahlen-produced ionization may be particularly effective at lower altitudes during auroral events (Chamberlain [4]).

Unfortunately the C-layer region in question, from 50 to 75 km., is too high for balloons and too low for satellites. The only direct measurements in this region are those made by infrequent and transient rocket probes. There is much to be learned of this region, particularly following solar flare explosions when such enormous amounts of energy are dissipated in the earth's atmosphere. It is not known, for example, whether corpuscular radiation produces a unipolar charge in or beneath the equivalent potential layer.

Solar "proton events" which are often associated with solar flares would seem more likely to produce a net positive charge. Large fluxes of solar protons were detected by satellite (Pieper, Zmuda, and Bostrom [16]) and rocket (Ogilvie, Bryant, and Davis [15]) measurements during the solar flare activity of July 1961 and November 1960. The extent to which such proton fluxes penetrate through the equivalent potential layer and whether or not there is an equal enhancement of the negatively charged electron density are not known.

Without additional knowledge of what effect corpuscular radiation has upon the earth-ionosphere spherical condenser, it becomes quite impossible to explain the post-flare acceleration of the leakage current within this condenser which has been detected at Mauna Loa.

5. STUDIES OF OTHER INVESTIGATORS

The solar-terrestrial relationship found at Mauna Loa has been found by others. One of the earliest investigations was that of Bauer [1] who collected potential gradient records in Europe for the years 1886 to 1923 and found that the electric field increased during periods of increased "sun-spottedness."

Much more recently, Reiter [18] made atmospheric electric measurements from several mountain sites in central Europe and reported a peak increase of about 5 percent for both the electric field and the air-earth current, usually occurring about 4 days after a solar flare. Reiter's measurements from 1956–1960 were made during the more active years of the 11-yr. solar cycle. It is significant that the monitored atmospheric electric climate at two widely separated mountain tops in Germany and Hawaii have both revealed the same solar-terrestrial correlation.

6. GLOBAL THUNDERSTORM ACTIVITY AND THE AIR-EARTH CONDUCTION CURRENT

Investigations of the earth-ionosphere electric circuit ultimately involve as the controlling parameter the global thunderstorm activity. As stated earlier, the current flow within the earth-ionosphere electrical circuit is, accord-

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ing to the classical concept, controlled and maintained by the global thunderstorm activity.

Through the years there have been several reports relating thunderstorm frequency and solar activity. Septer [21], Brooks [2], Flohn [9], and Reiter [18] have all found essentially the same correlation, that is, an increase in thunderstorm frequency during increased solar activity. More recently, Sartor [19], (in this issue), has found evidence relating the occurrence of sporadic E with heavy thunderstorm precipitation.

The investigations above, concerning increased thunderstorm activity and the solar flare-atmospheric electric relationship found at Mauna Loa and in Europe by Reiter, represent considerable evidence that both the earth-ionosphere conduction current and the global thunderstorm activity are increased by corpuscular solar radiation penetrating the earth's atmosphere.

The air-earth conduction current is governed by the basic Ohm's law relationship, $j=E\lambda$, where j is the air-earth current, E is the electric field, and λ is the conductivity. As explained in section 3, it is this thunderstorm generated "supply current" which maintains the charge balance on the positively charged equivalent potential layer and the negatively charged earth. What influence an increase in the basic current flow has on the thunderstorm activity is not known. It would be surprising, however, if an increase of 75 percent in the air-earth current, such as occurred during a 6-hr. period in July 1961, did not affect the thunderstorm activity either as a result of an increased efficiency of the individual storms or as an increase in the total number of storms. Any increase in the upward directed positive current beneath and above a thunderstorm would seem likely to enhance those interior thunderstorm electrical processes inherent in the separation of charge and the formation of rain (Gunn [11]).

The evidence presented in this report strongly suggests that corpuscular solar radiation exhibits a small but significant external influence on the earth-ionosphere electric circuit which is otherwise controlled and maintained by the global thunderstorm activity. The measured increase in the fair-weather air-earth current following solar flares must necessarily be accompanied by an increase in the return flow of positive charge to the equivalent potential layer and this return current will for the most part take place in regions of thunderstorm activity.

It has been estimated that as many as 3,600 thunderstorms are continually in existence (Gish and Wait [10]). Quite likely, there are as many potential storms which approach but never reach the thunderstorm stage. The global thunderstorm activity has never been adequately measured. Hopefully, satellite detection of spherics will soon provide a continuous measurement of this most important atmospheric electric parameter and help in explaining the solar-terrestrial phenomenon discussed here.

7. SUMMARY

The monitored atmospheric electric elements at Mauna Loa Observatory have provided good evidence of a direct solar influence on some of the electric elements recorded at the mountain Observatory. In the majority of occurrences, both the atmospheric electric field and the air-earth conduction current were increased above their mean values following solar flares. At present, there is not satisfactory explanation of the phenomenon. The answers lie in a better understanding of the effect of solar corpuscular radiation on the earth-ionosphere electric circuit.

The evidence found at Mauna Loa in Hawaii and at Zugspitze in Germany suggests that atmospheric electric measurements made from isolated mountain sites are more likely to respond to solar effects and changes within the earth-ionosphere spherical condenser. Because these mountains extend well into the more highly conducting atmosphere, the transfer of charge between the ionosphere and the mountain tops takes place with greater ease than from ionosphere to sea level.

It is important that such measurements be continued through both "quiet" and "disturbed" solar cycles.

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[Received June 28, 1967]